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Marginal Rail Infrastructure Costs in Finland 1997–2005

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ABSTRACT

This report studies the basic charge, which is part of the Finnish infrastructure charge levied on rail operators. The basic charge is set according to marginal infrastructure costs caused by traffic on the rail network. Marginal cost is equal to the change in variable infrastructure costs, when an additional unit of traffic uses the tracks. Marginal costs can be derived from cost functions of rail infrastructure management. The infrastructure costs included in the Finnish marginal cost analysis are maintenance and renewals on track sections. The Finnish analysis covers almost every track section on the state-owned rail network.

Cost functions and marginal costs should be assessed periodically for judging whether the level of the basic charge should be changed. The current level of the Finnish basic charge has been derived from cost functions estimated with cross section data for the years 1997–1999. A re-assessment has been made with cross section data for the years 1997–2002, but the results did not call for changes in the basic charge. In this report, results are presented from estimations with data for the years 1997–2005. Cost functions are estimated separately for the sum of maintenance and renewal costs, and maintenance costs only.

The results show, that *traffic on track sections (gross tonnes)* and *length of tracks (km)* have statistically significant explanatory power on variable infrastructure costs. According to cross section data (1997–2005), an increase in traffic by one percent raises variable infrastructure costs by 0.15–0.29 percent. An increase in the length of tracks by one percent raises variable infrastructure costs by 0.77–1 percent. According to panel data (1997–2005), the cost elasticities are 0.19 with respect to gross tonnes and 0.86 to the length of tracks.

The marginal infrastructure costs weighted by all track sections in the data are 0.07–0.18 cents/gross tonne kilometre (in prices of 2005), when derived from cross section cost functions (1997–2005) with both maintenance and renewal costs included. When derived from panel data, marginal costs are 0.09–0.14 cents/gross tonne kilometre accordingly, depending on the number of observations and specification of the cost function. The results indicate no need for adjusting the basic charge. The marginal costs for maintenance only are significantly lower than above.

The estimated cost functions are very simplistic. They should be developed further with variables that characterise the technical and quality differences between track sections. Such variables are e.g. the number of switches and the condition of tracks and switches. Classification of track sections by e.g. variables associated with service level should also be experimented on. Also, the dynamics of variable infrastructure costs should be analysed more in the future.

As the data allows the estimation of cost functions and marginal costs separately for maintenance and renewals, also separate pricing of these costs is possible, as well as the differentiation of charges on different parts of the network. The possibility of setting a charge on traffic on marshalling yards was also studied. Variable infrastructure costs can be identified for most marshalling yards, but the lack of data on traffic and technical features of the yards does not support the estimation of cost functions. As registers develop and provide data in the future, the issue should be re-adressed.

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TIIVISTELMÄ

Tässä työssä tarkastellaan Suomen ratamaksua. Tarkemmin käsitellään perusmaksun tasoa. Ratahallintokeskus perii perusmaksua rautatielain 13 § 1 momentissa tarkoitetuista tarjoamistaan palveluista ja muista hyödykkeistä. Perusmaksu on määritetty radan kulumisen rajakustannusten mukaan. Se tarkoittaa radanpidon kustannusten muutosta, joka aiheutuu liikenteen lisääntymisestä yhdellä suoriteyksiköllä. Suoritteiden vaikutus radanpidon kustannuksiin määritetään estimoimalla radanpidon kustannusfunktioita.

Perusmaksun taso on johdettu vuosien 1997–1999 aineistoilla estimoiduista kustannus-funktioista. Radanpidon kustannusfunktioita ja rajakustannuksia on tarkasteltava muutaman vuoden välein, jotta tiedetään, onko perusmaksun tasoa syytä muuttaa. Tarkastelu on sittemmin tehty vuosien 1997–2002 aineistoilla, mutta perusmaksun tasoa ei muutettu. Nyt kustannusfunktiota ja rajakustannusten tasoa tarkastellaan vuosien 1997–2005 aineistolla. Uusi aineisto on vuosilta 2003–2005.

Tulosten mukaan radanpidon kustannuksia selittäviä muuttujia ovat rataosan liikennemäärä (bruttotonnit) ja rataosan raidepituus. Vuosien 1997–2005 poikkileikkausaineistojen mukaan liikenteen lisäys yhdellä prosentilla kasvattaa radanpidon muuttuvia kustannuksia 0,15–0,29 prosenttia. Raidepituuden lisääminen prosentilla kasvattaa radanpidon muuttuvia kustannuksia 0,77–1 prosenttia. Yhdeksän vuoden paneliaineiston mukaan vastaavat joustot ovat 0,19 ja 0,86.

Vuosien 1997–2005 muuttuvien kokonaiskustannusten poikkileikkausaineistoista estimoidut radan kulumisen rajakustannukset ovat koko rataverkolle painottaen 0,07–0,18 snt/bruttotonnikilometri (vuoden 2005 hinnoissa). Tarkasteluajanjakson alussa rajakustannusten taso oli korkein, jonka jälkeen radanpidon rahoitustason muutos alensi rajakustannuksia. Vuodesta 2003 alkaen rajakustannusten taso nousi. Yhdeksän vuoden muuttuvien kokonaiskustannusten paneliaineistosta estimoidut koko rataverkolle painotetut radan kulumisen rajakustannukset ovat estimointitavasta ja otoksen koosta riippuen 0,09–0,14 snt/bruttotonnikilometri (vuoden 2005 hinnoissa). Perusmaksun taso vastaa siten vuoden 2005 hinnoissa esitettyjä tuloksia.

Radanpidon kustannusfunktioita tulisi kehittää muuttujilla, jotka kuvaavat rataosien teknisiä ja laadullisia eroja. Jatkossa voidaan kokeilla esimerkiksi vaihteiden lukumäärää sekä geometristä kuntoa kuvaavien muuttujien toimivuutta. Lisäksi rataosia voitaisiin luokitella esimerkiksi nopeustason ja kantavuuden mukaan.

Suomen aineistot sallivat rajakustannusten laskemisen ja ratamaksun asettamisen myös erikseen kunnossapitokustannusten ja korvausinvestointien pohjalta. Maksuja on lisäksi mahdollista asettaa jopa yksittäisille rataosille. Sen sijaan junakaluston rataa kuluttavien ominaisuuksien huomioon ottaminen ei onnistu tässä raportissa esitetyllä menetelmällä aineistosta riippuvista syistä. Vähän rataa kuluttavalle kalustolle myönnettäviä alennuksia tai paljon kuluttavalle kalustolle asetettavia lisämaksuja tulee pohtia teknisen tietämyksen pohjalta.

Työssä arvioitiin myös rajakustannusperusteisen perusmaksun määrittämistä ratapihojen liikenteelle. Tilastot ja rekisterit eivät tarjoa riittävästi tietoa kustannusfunktion muodostamiselle ratapihoilla. Suurimpien ratapihojen muuttuvat kustannukset tiedetään, mutta ratapihojen ominaisuuksia ja liikennesuoritteita ei voida määrittää riittävän hyvin. Liikennepaikka- ja vaihderekisterit sallivat ominaisuustietojen määrittelyn tulevaisuudessa. Suoritetiedot on määritettävä laajentamalla rautatietilastointia ratapihojen liikenteeseen.

Foreword

In 2006, the Finnish Rail Administration conducted a study on marginal rail infrastructure costs with data from 1997–2005. This report is an English summary of some of the main results. Two similar studies have been conducted earlier with data from 1997–2002.

The main goal of the study was the assessment of marginal rail infrastructure costs and comparison of the results with the level of the current basic infrastructure charge levied on rail operators.

Members of the Steering Committee of the study were Martti Kerosuo (Chairman), Laura Kuistio, Matti Nissinen, Harri Lahelma, and Pentti Hirvonen from the Finnish Rail Administration and Tuomo Suvanto from the Ministry of Transport and Communications.

The project consultants were M.Sc. Econ. Juha Tervonen (JT-Con) and Ph.D. Econ. & Bus. Admin. Saara Pekkarinen (SP Research).

Helsinki, in May 2007

Finnish Rail Administration

Traffic system department

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1 Introduction

The Finnish Rail Administration collects a *basic infrastructure charge* from rail operators. Other infrastructure charges are the *infrastructure tax* and the *investment tax*. The basic infrastructure charge covers the minimum access package, which includes access to service facilities on the state-owned rail network (Finnish Rail Administration, 2005).

The current level of the basic infrastructure charge has been set according to marginal rail infrastructure costs caused by an additional unit of traffic (gross tonne kilometre) using the rail network. The costs considered in the analysis only include those costs that are variable in the short-term. These are maintenance and renewal costs. Furthermore, only variable infrastructure costs on lines (track sections) are considered. Infrastructure costs on marshalling yards and associated sidings are excluded.

First, cost functions are estimated for rail infrastructure management. Then, marginal infrastructure costs are derived from the fitted cost function. As marginal costs are derived for each track section (observation) in the data, a weighted value representing marginal costs on the whole network, is then calculated for pricing purposes.

Originally, Idström (2002) estimated marginal rail infrastructure costs as cross sections for the years 1997–1999. The current basic infrastructure charge is based on the results of this study. In another study (Tervonen & Idström, 2004), the estimation was repeated with data for the years 1997–2002. The results did not indicate need for adjusting the basic infrastructure charge.

Now, cost functions are estimated with data for the years 1997–2005. Once again, the purpose of the study is to compare weighted marginal costs with the level of the basic infrastructure charge. Also, there is opportunity to test different formulations of the cost functions with a larger set of data than before. In previous studies, cost functions were estimated with cross section data and pooled data (six years). Now, cost functions are estimated with cross section data for nine separate years and panel data, which combine all nine years.

This report describes the system of Finnish infrastructure charges and the methodology used for estimating cost functions for rail infrastructure management, as well as the derivation of marginal infrastructure costs. Estimations are made separately with the sum of all variable costs (maintenance and renewals), and maintenance costs only. Results on the prior cost category are relevant for current charges in Finland. Results on the latter cost category are relevant for examining the cost structure of rail infrastructure management in the short-term. As indicated, some estimation results are presented in fixed prices (the prices of 2005) and some in nominal prices.

2 Finnish Infrastructure Charge

Rail infrastructure charges have been collected in Finland since 1990. Changes aligning the charging system with railway directives and national laws (Directive 2001/14/EC in particular; e.g. Finnish Law on Railways, Finnish Law on Network Taxes and Act on Basic Infrastructure Charge) have been made along the way.

The current Finnish infrastructure charges are shown in Table 2.1. The basic charge is set according to marginal infrastructure costs derived from cost functions for the years 1997–1999 and weighted over the network by traffic volumes (Idström, 2002).

The infrastructure tax, a mark-up, has partial origins in external costs of railway traffic. The investment tax is collected on a new line (opened in 2006) during a fixed period for covering a part of the investment costs.

All charges are collected by the Finnish Rail Administration. Income from the basic charge is managed by the Finnish Rail Administration. Income from taxes is directed to the Ministry of Finance. In 2005, income from the basic charge was M€ 40.6, and income from the tax was M€ 15.5. The total budget of the Finnish Rail Administration in 2005 was M€ 495.

Table 2.1. Infrastructure charges in Finland (Finnish Rail Administration, 2005)

	Charge, cents/gross tonne kilometre
Basic charge	Freight traffic: 0.1227 Passenger traffic: 0.1189
Infrastructure tax	Freight traffic - electric: 0.05 - diesel: 0.1 Passenger traffic: 0.01
Investment tax (track section: Kerava–Lahti)	Freight traffic: 0.5 Passenger traffic: 0.5

3 General description of the method and Finnish data

3.1 Steps of the method

The expert advisors of the European Commission have outlined a best practice for defining efficient rail infrastructure charges (European Commission, 1999). The Finnish application includes the following phases:

- Infrastructure costs are sorted into variable and fixed costs in the short-term.
- The network is partitioned into track sections.
- Variables assumed to explain variable infrastructure costs are identified for formulating a cost function.
- Data on variable infrastructure costs and the explanatory variables is collected at the level of track sections.
- Cost functions are estimated, and the variables with explanatory power on variable infrastructure costs are revealed.
- The cost function is differentiated with respect to traffic volume, which reveals the marginal cost caused by a change in traffic on each track section.
- Weighted marginal costs are calculated over the network (or parts of it) by using traffic volumes on track sections as weighting factors.

Besides Finland, the method has also been empirically applied in Austria (Munduch et al., 2002), in France (Gaudry & Quinet, 2003) and in Sweden (Johansson & Nilsson, 2004; Andersson, 2005).

Successful estimation depends on volume and quality of data. Partitioning of the network (data) should allow for studying differences in marginal costs on track sections that are diverse in variable costs, traffic volumes and technical features. Time series are needed for revealing variations in cost functions and marginal costs.

3.2 Classification of variable and fixed costs

Marginal rail infrastructure costs are derived from costs that vary in the short-term by trains using the tracks. The categorisation of variable and fixed costs in the Finnish studies is aligned with the principles presented by the European Commission (Table 3.1), but some further judgements have also been made.

In Finland, variable infrastructure costs include all maintenance and renewals costs on lines (track sections), including winter maintenance. Administrative costs are considered fixed, as well as the costs of authorities external to rail administration (e.g. police). Timetabling is excluded, since it is a cost of the operator. Operation of the network (e.g. cost of electricity for operating and heating switches) and traffic control (mainly personnel and electricity costs) are considered fixed. Variable costs in the Finnish studies are described in more detail in section 3.3.

Table 3.1. Classification of rail infrastructure costs (adopted from the European Commission, 1999)

Cost category	Fixed	Variable by infrastructure use and the number of trains/vehicles
Land purchase	yes	no
Construction of new lines	yes	no
Upgrading/extension of existing lines	yes	no
Renewals/replacement investments		
Major repairs		
- periodical treatment of structures	partly	partly
- major repairs of bridges, tunnels, switch boxes and platforms performed at larger intervals	partly	partly
Renewal		
- major repairs of bridges, tunnels, switch boxes and platforms, tracks and other facilities which restore full utility value	partly	partly
Construction maintenance		
- minor repairs of bridges, noise protection walls, technical facilities	no	partly
- ballast cleaning, compression	no	partly
Ongoing maintenance and operation		
- winter maintenance	yes	partly
- cleaning, cutting	yes	no
- facility condition checks	yes	partly
- service of bridge beddings, signaling, telecommunications facilities, switch towers	yes	no
- traction current	mainly no	yes
Administration		
- overhead	yes	no
- police	no	yes
- time tabling, train planning	no	yes

3.3 Description of data

The original data template consists of 93 track sections (see Annex). Most Finnish statistics and registers are available for such a partitioning of the network. Tracks on marshalling yards, as well as tracks linking the state network with private industrial yards and ports, are excluded. Some inferior track sections are omitted from the data template with time due to ceasing traffic and/or statistical monitoring.

There are 5 626 kilometres of rail lines in the data template, while the length of the entire network maintained by the Finnish Rail Administration is 5 850 kilometres

(Table 3.2, Figure 3.1). The length of the track sections varies from 3 to 200 kilometres. Due to sections with multiple tracks, the total length of tracks in the data is 7 514 kilometres.

Table 3.2. Rail network and traffic in Finland in 2005 (Finnish Rail Administration, 2006)

Network length, kilometres	5 732
Total track length, kilometres	8 587
Length of multiple track network, kilometres	507 km (9 %)
Length of electrified network, kilometres	2 617 km (46 %)
Train kilometres (1 000)	48 227
- Passenger trains	31 408 (65 %)
- Freight trains	16 819 (35 %)
Gross tonne kilometres (1 000 000)	33 444
- Passenger trains	11 201 (34 %)
- Freight trains	22 243 (66 %)

The following information is collected for each track section:

- length in kilometres,
- length of tracks in kilometres,
- various technical features and service/quality level indicators,
- traffic in gross tonnes per annum – separately for freight and passenger trains,
- maintenance costs per annum (as a lump), and
- renewal costs per annum (as a lump).

Features of the track sections are defined according to network statements. Some variables are fixed by nature. If a variable is subject to changes from year to year, the information is checked for each cross section. Traffic data is compiled from railway statistics. Gross tonnes per track section include the cumulative gross weight of trains (engines, cars, load and passengers) that have passed through a section during a year. Gross tonnes are collected separately for passenger trains and freight trains, but in estimation all gross tonnes are summed up. Variable costs are available from cost follow-up summary reports by track section.

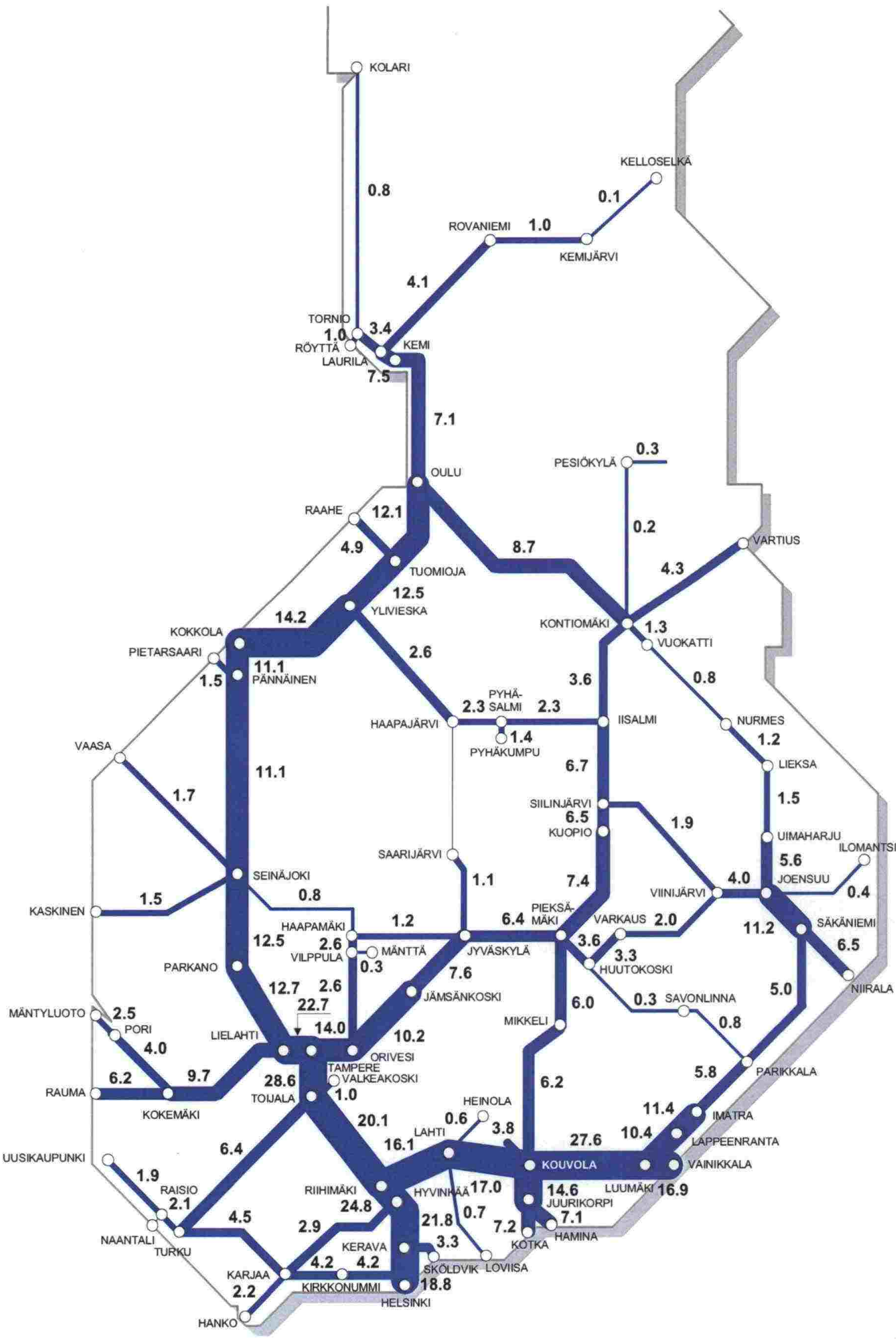

Figure 3.1. Finnish rail network and gross tonnes carried (million) on lines in 2005 (excluding electrically powered commuter trains; Finnish Rail Administration)

Table 3.3 presents technical features of track sections available in registers. There are several variables available for describing technical quality and service levels. As the results in section 4 indicate, the potential performance of many of the variables has not necessarily been revealed yet, and opportunities remain for further research.

Table 3.3. Technical and quality features of track sections

Variable	**Indicator**
Length of track section (geographical)	kilometre
Length of tracks on section	kilometre (with multiple tracks accounted for)
Multiple tracks	number
Electrification	yes/no
Technical quality/level of service	e.g. classification of materials by technical vintage, condition index, service level categories
Switches	number
Maximum axle load	tonnes
Maximum speed	speed limit

Variable costs include following undertakings on track sections:

- *Maintenance* consists of daily maintenance, repairs and on-calls. Also, small scale replacements of structures, equipment and devices are included.
- *Renewals* consist of extensive renewing of structures, equipment and devices, which are at the end of their technical and/or economic life-cycle.

Table 3.4 presents the annual volumes of variable infrastructure costs in the data as totals for all track sections. The volume of costs varies from year to year mainly due to changes in the budget, but also e.g. cost efficiency targets have an impact. Depending on the year, also e.g. stations and marshalling yards may have a larger emphasis in renewal programs leaving less budget for renewals on lines.

It must be noted, that variable infrastructure costs on lines are a fraction of the total budget of the Rail Administration. For example in 2005, the total budget was M€ 495 (including new investments).

Table 3.4. Variable costs on track sections in this study (M€ in prices of 2005)

M€	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Maintenance	80	74	73	54	57	58	74	80	60
Renewals	175	194	158	130	105	122	84	102	97
Total	**255**	**268**	**231**	**184**	**162**	**180**	**158**	**182**	**157**

4 Cost functions and marginal costs

4.1 Formulation of the cost function

Cost functions are based on the Cobb-Douglas (CD) formulation and its generalization, the more flexible Translog (TL) formulation (Caves et al., 1980; Pollak et al., 1984). Similar methodology has been used e.g. in Sweden (Johansson & Nilsson, 2004) and Austria (Munduch et al., 2002).

The statistical relationship between variable infrastructure costs and the explanatory variables can be expressed for each observation [track section (i) and year (t)] as

$$C_{it} = g(Y_{it}, U_{it}, Z_{it}, d_{it}, \varepsilon_{it}) \tag{1}$$

where C_{it} = variable infrastructure costs on track sections
Y_{it} = length of tracks by track section (km with multiple tracks accounted for)
U_{it} = traffic volume by track section (gross tonne)
Z_{it} = features of track sections (e.g. number of switches, maximum speed, maximum load, electrification, technical condition)
d_{it} = dummy variable for depicting differences between track sections (by volume of variable costs)
ε_{it} = error terms and
g = mathematical function.

Variable costs include either the sum of maintenance and renewal costs, or only maintenance costs. The volumes of infrastructure, as well as traffic volumes, are homogenous variables. In each Finnish marginal cost study, data has been collected on features of the track sections. In estimations, however, the statistical performance of these variables has not been satisfactory. Hence, a dummy variable has been created for compensating the lack of well-performing quality variables.

A corresponding regression model in logarithmic form based on CD is expressed as

$$\ln C_{it} = \alpha + \beta_y y_{it} + \beta_u u_{it} + \beta_k d_{it}^k + \varepsilon_{it} \tag{2}$$

Variable infrastructure costs are explained by the logarithms of length of tracks y (km) and traffic volume u (gross tonne). The dummy variable, $d_{it}^k, k = 1$, is assigned the value one (1), when renewals on a track section exceed 16 819 €, and otherwise its value is zero (0). An analogous dummy is formulated also in estimations on maintenance costs, but with a different threshold.

Equation (2) is estimated by the Least Squares method (LS) that will give unbiased and consistent estimates of parameter coefficients (β) of the explanatory variables expressing the impact on variable infrastructure costs. For logarithmic variables, the estimated coefficients are elasticities. For example, the coefficient of traffic volume (β_u) is called *cost elasticity* of utilization.

The CD is a restricted case of the TL specification[1], which can be expressed as

$$\begin{aligned}\ln C_{it} &= \alpha + \beta_y y_{it} + \beta_u u_{it} + \beta_z \mathbf{z}_{it} + 0.5\beta_{yy} y_{it}^2 + 0.5\beta_{uu} u_{it}^2 + \beta_{yu} y_{it} u_{it} \\ &+ \beta_{zy} \mathbf{z}_{it} y_{it} + \beta_{zu} \mathbf{z}_{it} u_{it} + \varepsilon_{it},\end{aligned} \tag{3}$$

where vector z_{it} consists of the quality features of and dummy for differences between track sections. Starting from specification (3) and setting restrictions as $\beta_{yy} = \beta_{uu} = \beta_{yu} = 0$, $\boldsymbol{\beta}_{zu} = \boldsymbol{\beta}_{zu} = 0$, it is possible to test whether the TL cost function can be rejected in favour of a more restricted functional form.

4.2 Derivation of marginal costs

Once the cost function has been defined, it possible to derive marginal costs per unit of traffic. The suitable unit is gross tonne kilometre. It is calculated by multiplying gross tonnes on a track section with the length of the section. So, $Q_{it} = L_{it} \cdot U_{it}$.

When track length is constant, the cost function can be partially derivated with respect to gross tonne kilometres as

$$\frac{\partial \hat{C}_{it}}{\partial Q_{it}} = \frac{1}{L_{it}} \frac{\partial \left[\exp(\hat{\alpha} + \hat{\beta}_y y_{it} + \hat{\beta}_u u_{it} + z_{it}\hat{\beta}_z + 0.5\hat{\sigma}^2\right]}{\partial U_{it}} = \hat{\beta}_u \frac{1}{L_{it} U_{it}} \cdot \hat{C}_{it} \tag{4}$$

where the fit $\hat{C}_{it}$ for variable infrastructure costs is calculated based on the results of the regression model (2) as $\hat{C}_{it} = \exp(\hat{\alpha} + \hat{\beta}_y y_{it} + \hat{\beta}_u u_{it} + \mathbf{z}_{it}\hat{\boldsymbol{\beta}}_z + 0.5\hat{\sigma}^2)$, where $\hat{\sigma}^2$ is the estimate on the variance of the error term (see Munduch et al., 2002). Transforming equation (4) yields the estimated cost elasticity of utilization of rail infrastructure as

$$\hat{\beta}_u = \frac{\partial \hat{C}_{it}}{\partial Q_{it}} \cdot \frac{Q_{it}}{\hat{C}_{it}} \tag{5}$$

The estimate of marginal costs for each track section can now be calculated as

$$MC_{it} = \hat{\beta}_u \frac{\hat{C}_{it}}{Q_{it}}. \tag{6}$$

As marginal costs vary by track section and from year to year, it is justifiable to calculate weighted values for marginal costs e.g. for all track sections. Traffic volume can be used as a weight: $w_{it} = Q_{it} / \sum_i Q_{it}$.

Weighted marginal cost for all track sections is expressed as

$$\overline{MC}_{it} = \hat{\beta}_u \sum_i \frac{\hat{C}_{it}}{\sum_i Q_{it}} = \sum_i \hat{\beta}_u (\frac{\hat{C}_{it}}{Q_{it}}) * w_{it} = \sum_i MC_{it} * w_{it} \tag{7}$$

[1] The Translog specification (Pollak et al., 1984) is, in turn, a special case of a so-called Unrestricted Generalized Box-Cox form (see e.g. Gaudry and Quinet, 2003).

4.3 Results

4.3.1 Cross section data with all variable costs

First, the CD cost functions specified in eq. (2) were estimated as cross sections for each year from 1997 to 2005 with all variable costs included. The results in Table 4.1 reflect the changes that occur in cost functions and weighted marginal costs as variable infrastructure costs and traffic volumes change from year to year.[2]

All estimated parameters have expected sign and are significant at the level of 5 %. The number of observations varies because some track sections are dropped from the data. This does not impact the coefficient of determination. The adjusted R^2 varies between 0.48 and 0.63, which is satisfactory for cross-section data (Munduch et al., 2002; Johansson & Nilsson, 2004).

Cost elasticity with respect to gross tonnes varies between 0.13 and 0.25, which is evidence of economies of scale with respect to traffic volumes. Nonetheless, infrastructure costs are inelastic with respect to track lengths with cost elasticity varying between 0.75 and 0.99. The dummy indicates strong relationship between the volume of renewals and cost variation across track sections.

Marginal costs weighted for all track sections vary from 0.07 to 0.18 cents/gtkm depending on the cross section. This reflects changes in the volume of variable costs from year to year. This, in turn, is due to changes in renewal budgets in particular (see Table 3.4).

Table 4.1. Parameter estimates from cross section models for 1997–2005, maintenance and renewal costs costs included (in prices of 2005; standard errors in brackets)

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Constant	5.847	6.803	7.028	6.137	6.296	6.455	7.793	8.254	5.710
	(1.041)	(1.214)	(1.199)	(1.293)	(1.263)	(1.053)	(1.081)	(1.182)	(1.157)
lnGross tonnes	0.248	0.214	0.199	0.204	0.199	0.205	0.155	0.131	0.211
	(0.059)	(0.073)	(0.072)	(0.075)	(0.070)	(0.058)	(0.062)	(0.064)	(0.071)
lnTrack length	0.919	0.811	0.813	0.920	0.904	0.874	0.791	0.751	0.991
	(0.117)	(0.131)	(0.131)	(0.147)	(0.128)	(0.130)	(0.106)	(0.132)	(0.108)
Dummy	1.128	1.083	0.824	0.952	0.979	0.907	0.762	0.977	0.951
Renewals	(0.168)	(0.209)	(0.217)	(0.217)	(0.184)	(0.179)	0.192)	(0.199)	(0.170)
No. obs.	91	91	91	90	86	88	86	86	86
Adjusted R^2	0.629	0.542	0.487	0.477	0.553	0.545	0.606	0.541	0.614
F-statistics	51.93	36.47	29.48	28.07	36.12	35.76	44.62	34.35	46.15
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Weighted MC, cents/gtkm	0.180	0.160	0.149	0.103	0.096	0.093	0.070	0.070	0.094

[2] Variations occur at both aggregate level and at the level of individual track sections.

The level of renewals apparently also impacts cost elasticities with respect to traffic. However, it must be taken into account, that in the models estimated, cost elasticities and marginal costs reflect the combined impact of the volume of traffic and the volume of variable costs on individual track sections, which both change from year to year.[3]

As traffic volumes are relatively balanced, the changes in variables costs (and specifically renewals) are more significant. Each year renewals are undertaken on approximately 50–60 % of the track sections in the data. On average, renewals double the volume of variable costs on a particular track section for the particular year.[4]

4.3.2 Cross section data exclusively with maintenance costs

Maintenance has different characteristics as compared to renewals. Maintenance is an on-going activity, which takes place on each track section every year. So, maintenance costs are balanced from year to year both at the aggregate level and at the level of individual track sections. In turn, renewals are implemented periodically, and the volume of the money used per track section depends on the types of undertakings. Cross sections for 2003, 2004 and 2005 were estimated for highlighting the difference in cost functions estimated for different cost entities.

The specification of the empirical function of maintenance costs is identical to the specification presented in eg. (2), except that the variable d^k is now the dummy for the volume of maintenance costs and z is the log of the number of switches. Since experiments on the number of switches were based on inaccurate data, the formulation was rejected.[5] Instead, the results of models without switches (basic model) are shown. Note, that now the estimations are based on data with costs in nominal prices.

The models in Table 4.2 fit the data well, best for the 2005 data. All the parameter estimates are highly significant. Cost elasticity of maintenance with respect to gross tonnes varies between 0.12 and 0.18. Cost elasticity of maintenance with respect to track length varies between 0.72 and 0.93. From comparison to results on cross sections 2003–2005 in Table 4.1, it is seen that the marginal costs of maintenance only account for approximately one-third of marginal costs with renewals included.

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[3] When renewals are large and there is low traffic, marginal costs per gtkm are high, and vice versa.

[4] It must be noted, that the allocation and timing of renewals is impacted by various underlying factors. Renewals may be undertaken separately by e.g. renewing surface structures and rail materials one year, and devices and equipments the next year. Renewals are also planned and scheduled for minimising traffic disturbances.

[5] There are indications of the *number of switches* being a potentially strong explanatory variable, but it remains a future research issue until the register on switches is completed.

Table 4.2. Parameter estimates from cross section models 2003–2005, only maintenance costs included (in nominal prices; standard errors in brackets)

	2003	**2004**	**2005**
Constant	7.506	7.472	6.397
	(0.644)	(0.765)	(0.799)
lnGross tonnes	0.159	0.118	0.178
	(0.035)	(0.042)	(0.047)
lnTrack length	0.721	0.877	0.928
	(0.113)	(0.093)	(0.099)
Dummy for maintenance cost volume	0.426	0.442	0.451
	(0.114)	(0.157)	(0.141)
No. obs.	86	86	86
Adjusted R^2	0.555	0.583	0.687
F-statistics (p-value)	36.33(0.000)	40.65(0.000)	63.15(0.000)
Weighted MC, cents/gtkm	0.031	0.026	0.033

4.3.3 Panel data with all variable costs

Panel data allows accounting for unobserved differences in average variable costs across track sections (fixed effects model) or unobserved variation in infrastructure costs due to factors not included in the regression model. In random effect models the random error can be either track-section specific or time-period specific. Now, the random effects period-specific model is used besides the ordinary pooled model.

The panel data (1997–2005) is used for estimating cost functions for variable costs (maintenance and renewals) with CD and TL specifications. The results are presented in Table 4.3.

First, the CD cost function [eq. (2) in section 4.1] is estimated by panel LS (Model 1) and then by EGLS (Model 2).[6] The estimated parameter values are very close to each other, and Model 2 fits the data slightly better.

Then, the full TL cost function (eq. 3 in section 4.1) is estimated as the period-specific random effects model by EGSL method (Model 3). For the restrictions $\beta_{yy} = \beta_{uu} = 0; \beta_{uy} = \beta_{yz} = 0$, Chi-square test statistics is 4.411 (p-value=0.353) with four degrees of freedom. This indicates that the full TL specification can be rejected.

Therefore, three restricted TL models are estimated to test the impact of sample size (number of track sections; Models 4 and 5) and the impact of the lagged dependent variable on all variable costs (Model 6). Again, the estimated parameters for gross tonnes and track length are very similar in the restricted Models 4 and 5. Inclusion of the lagged dependent variable changes all estimated parameter values in Model 6.

[6] Eviews 5.1 User's Guide.

The cost elasticity with respect to gross tonnes is approximately 0.18 estimated by CD in Models 1 and 2. Cost elasticities with respect to gross tonnes from restricted TL models (Models 4, 5 and 6) vary between 0.11 and 0.13. on track sections with renewals, and between 0.22 and 0.27 for track section with very low or zero renewals.

The marginal costs weighted for all track sections in the panel vary between 0.09 and 0.14 cents/gtkm (in fixed prices) depending on model specification. The marginal costs estimated from cross sections 1997–2005 (in section 4.3.1) are within the same range, except for the cross section 1997.

Table 4.3. Estimation results of pooled (LS) and panel random error models (EGSL) results for all variable costs included 1997–2005, in prices of 2005 (standard errors in brackets)

Variable	Model 1 CD	Model 2 CD	Model 3 TL	Model 4 TL	Model 5 TL	Model 6 TL
Constant	7.011	6.959	6.571	7.749	7.656	4.932
	(0.366)	(0.364)	(1.541)	(0.434)	(0.224)	(0.356)
lnGross tonnes	0.179	0.181	0.294[a]	0.127	0.133	0.070
	(0.021)	(0.021)	(0.146)	(0.026)	(0.014)	(0.019)
lnTrack Length	0.855	0.859	0.929	0.859	0.859	0.524
	(0.042)	(0.041)	(0.560)	(0.041)	(0.022)	(0.046)
DummyRenewals	0.961	0.955	-1.512[a]	-1.204[b]	-1.015[c]	-0.338[d]
	(0.062)	(0.017)	(0.789)	(0.648)	(0.600)	(0.621)
$(\text{lnGross tonnes})^2$	-	-	-0.014	-	-	-
			(0.011)			
$(\text{lnTrack Length})^2$	-	-	-0.037	-	-	-
			(0.076)			
(lnGross tonnes)	-	-	0.005	-	-	-
(lnTrack Length)			(0.027)			
(lnGross tonnes)	-	-	0.165[a]	0.142	0.130	0.069[e]
(DummyRenewals)			(0.037)	(0.648)	(0.040)	(0.040)
(lnTrackLength)	-	-	-0.009	-	-	
(DummyRenewals)			(0.088)			
lnGrossTonnes(t-1)	-	-	-	-	-	0.375
						(0.040)
No. obs.	808	808	808	808	773	686
Adjusted R^2	0.558	0.565	0.538	0.571	0.544	0.613
F-statistics	340.02	349.71	113.17	269.09	231.26	218.01
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Cost elasticity w.r.t ouput	0.179	0.181	-	0.127	0.133	0.112
				0.268	0.263	0.222
Weighted MC, cents/gtkm	0.099	0.010	-	0.136	0.107	0.092

[a] [a] Not significant at 5%. [b] Significant at 10%, all others significant at 0.1%. [c] Significant only at 10%. [d] Coefficient of Dummy(Renewals) not significant. [e] Significant at 10%.

4.3.4 Panel data exclusively with maintenance costs

The cost function for maintenance costs was estimated as a panel for 1997–2005, with the same formulation as in section 4.3.2 (basic model without the variable for the number of switches). The estimations are based on cost data in fixed prices of 2005.

As shown in Table 4.4, in the panel cost elasticity of maintenance with respect to gross tonnes is 0.12. Cost elasticity of maintenance with respect to track length is 0.83.

Weighted marginal costs of maintenance are approximately 0.03 cents/gtkm, which is within the range of marginal costs calculated for cross sections 2003–2005 (in section 4.3.2). Again, the results reflect the changes that took place in maintenance budgets (see Table 3.4).

Table 4.4. Parameter estimates from panel model 1997–2005 with only maintenance costs included (in prices of 2005)

	Cobb-Douglas
Constant	7.549 (0.211)
lnGross tonnes	0.123 (0.012)
lnTrack Length	0.831 (0.025)
DummyRenewals	0.548 (0.035)
No. obs.	806
Adjusted R^2	0.663
Weighted MC, cents/gtkm	0.026

5 Review of methodology and results

The CD cost function performs well with Finnish data. Thus, there is no reason to reject the basic formulation. Nevertheless, more flexible formulations should be sought in future studies. Finnish data on basic variables (variable costs, traffic volumes and basic characteristics of the track sections) is also of good quality.

A major challenge of the basic cost function formulation concerns the inclusion of variables, which can capture the impact of technical and quality diffences of track sections on variable infrastructure costs. The basic model may reveal only limited information on cost relationships.

There are theoretical and empirical assessments that point out the relevance of technical and quality variables on cost functions of railway infrastructure management (e.g. Gaudry & Quinet, 2003). In Finnish studies, some indication has been found on the performance of variables such as the *number of switches* and *maintenance levels*. Also, measurement data on *geometrical condition of tracks and switches* may be prospective.

In support of the main objective of this study, the results shown here are mainly based on a static model and long-term equilibrium. Some trials were made for estimating dynamic (lagged) models.

The main objective of the study was the comparison of weighted marginal costs with the level of the basic infrastructure charge. The results do not indicate a need to change the level of the charge.

The Finnish data allows separate pricing of maintenance and renewals costs. Charges could also be differentiated e.g. for track sections with different levels of service. These remain a future option.

In many countries, charges are differentiated for the types of rolling stock. Unfortunately, the Finnish data does not support such marginal cost analysis. Almost all track sections are in multiple use, and data cannot be segmented for analysis on different types of traffic.

A review was made on the possibility of estimating cost functions on marshalling yards. The conclusion is, that at the moment registers do not support such studies. Variable costs on main marshalling yards are known, but data on traffic and characteristics of marshalling yards is insufficient.

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ANNEX 1 Track sections in the Finnish data

No.	Section	Length, km	No.	Section	Length, km
1	Helsinki - Pasila	3	48	Säkäniemi - Border	33
2	Pasila - Hiekkaharju	14	49	Joensuu - Ilomantsi	71
3	Hiekkaharju - Kerava	12	50	Turku - Toijala	128
4	Pasila - Kirkkonummi	35	51	Toijala - Valkeakoski	17
5	Huopalahti - Vantaankoski	9	52	Pieksämäki - Jyväskylä	80
6	Kerava - Hyvinkää	30	53	Toijala - Tampere	40
7	Hyvinkää - Riihimäki	12	54	Vilppula - Mänttä	9
8	Kerava - Sköldvik	33	55	Lielahti - Kokemäki	91
9	Kirkkonummi - Karjaa	49	56	Kokemäki - Pori	38
10	Hyvinkää - Karjaa	99	57	Tampere - Lielahti	6
11	Karjaa - Hanko	53	58	Lielahti - Parkano	69
12	Riihimäki - Toijala	76	59	Parkano - Seinäjoki	84
13	Riihimäki - Lahti	59	60	Kankaanpää - Parkano	48
14	Turku - Raisio	8	61	Parkano - Aitoneva	22
15	Raisio - Uusikaupunki	58	62	Tampere - Orivesi	42
16	Karjaa - Turku	113	63	Orivesi - Jämsänkoski	60
17	Lahti - Kouvola	62	64	Jämsänkoski - Jyväskylä	53
18	Kouvola - Juurikorpi	36	65	Orivesi - Haapamäki	72
19	Juurikorpi - Kotka	18	66	Haapamäki - Seinäjoki	118
20	Kouvola - Luumäki	58	67	Kokemäki - Rauma	47
21	Kouvola - Mikkeli	113	68	Pori - Mäntyluoto/Tahkoluoto	21
22	Mikkeli - Pieksämäki	71	69	Jyväskylä - Äänekoski	47
23	Kouvola - Kuusankoski	8	70	Äänekoski - Saarijärvi	28
24	Juurikorpi - Hamina	19	71	Saarijärvi - Haapajärvi	135
25	Lahti - Heinola	38	72	Jyväskylä - Haapamäki	78
26	Lahti - Loviisa	78	73	Seinäjoki - Vaasa/Vaskiluoto	74
27	Luumäki - Vainikkala	33	74	Seinäjoki - Kaskinen	112
28	Luumäki - Lappeenranta	28	75	Seinäjoki - Kokkola	133
29	Lappeenranta - Imatra	39	76	Kokkola - Ylivieska	79
30	Imatra - Parikkala	61	77	Ylivieska - Tuomioja	68
31	Parikkala - Säkäniemi	93	78	Tuomioja - Oulu	54
32	Säkäniemi - Joensuu	37	79	Pännäinen - Pietarsaari	11
33	Parikkala - Savonlinna	59	80	Tuomioja - Raahe/Rautaruukki	34
34	Savonlinna - Huutokoski	75	81	Ylivieska - Haapajärvi	55
35	Pieksämäki - Kuopio	89	82	Oulu - Kontiomäki	166
36	Kuopio - Siilinjärvi	25	83	Oulu - Kemi	106
37	Siilinjärvi - Iisalmi	60	84	Kemi - Laurila	8
38	Pieksämäki - Huutokoski	31	85	Laurila - Rovaniemi	106
39	Huutokoski - Varkaus	18	86	Laurila - Tornio	18
40	Varkaus - Viinijärvi	101	87	Tornio - Kolari	183
41	Viinijärvi - Joensuu	33	88	Tornio - Röyttä	11
42	Viinijärvi - Siilinjärvi	112	89	Rovaniemi - Kemijärvi	83
43	Iisalmi - Kontiomäki	109	90	Kemijärvi - Kelloselkä	78
44	Iisalmi - Haapajärvi	99	91	Murtomäki - Otanmäki	25
45	Joensuu - Uimaharju	50	92	Taivalkoski - Kontiomäki	156
46	Uimaharju - Nurmes	109	93	Kontiomäki - Vartius	95
47	Nurmes - Kontiomäki	109		**Total length**	**5 626**

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